## A new correlation for the viscosity of R134a

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### **ABSTRACT**

A new correlation for dynamic viscosity of R134a:

$$h = \sum_{i=0}^{N1} f_i(T_r) r_r^i$$

is proposed in this paper.

The correlation has been tested by 256 experimental data. These data are in the temperature range from 213K to 423K, and the pressure range from 0.1MPa to 50 MPa. The overall mean deviation between the experimental and the calculated data is 2.15%. The mean deviation in the subcooled liquid phase ,saturated liquid phase and superheated vapor phase is 2.486%, 1.4%, and 0.24% respectively. The result show this correlation is in excellent agreement with the experimental data, particularly in vapor phase . This correlation is valid in both liquid and vapor phase.

KEYWORD: correlation; deviation; R134a; dynamic viscosity

### 1. INTRODUCTION

Being one of the alternatives of R12 ,R134a has been applied in the car's air-conditioning system. Because it's a new refrigerant ,the study on dynamic viscosity of R134a is not enough, and the correlations proposed to calculate the dynamic viscosity of R134a are not valid in wide application range. All these may be disadvantageous to optimization design and dynamic simulation. So, in this paper the authors study the dynamic viscosity of R134a ,and propose a new correlation for

viscosity of R134a.

### 2. EXPERIMENTAL STUDIES ON DYNAMIC VISCOSITY OF R134a

Reports that have been published about the dynamic viscosity of R134a are listed as below:

In 1991, using a designed capillary viscometer, Kumagai<sup>[1]</sup> measured the saturated liquid dynamic viscosity of R134a in the temperature range from 273K to 353K, and obtained 8 data. According to the report, the uncertainty of the measurement was 0.5%, and the purity of the sample was 99.8%.

Lavrenchenko<sup>[2]</sup> measured the dynamic viscosity of R134a in both liquid and vapor phase, and obtained 34 experimental data in 1992. These experimental data are in the temperature range from 257.88K to 404.59K, and the pressure range from 0.318MPa to 6.437MPa.

In 1991, using a capillary viscometer, Okubo<sup>[3]</sup> measured the subcooled liquid dynamic viscosity of R134a. In the temperature range from 213K to 423K, and he obtained 81 data. AccordIng to the report, the uncertainty of the measurement was less than 1.3%, and the purity of the sample was greater than 99.8%.

In 1991, using a vibrating-wire viscometer, Oliveire<sup>[4]</sup> measured the liquid dynamic viscosity of R134a. In the temperature range from 237.74K to 343.15K and the pressure range from 0.664MPa to 50MPa, he obtained 60 data. According to the

sample was greater than 99.9%.

In 1992 ,Diller<sup>[5]</sup> measured the liquid dynamic viscosity of R134a. The measurement in the saturated liquid phase was performed in the temperature range from 175K to 320K, and they obtained 30 saturated liquid dynamic viscosity data The measurement in subcooled liquid phase was performed in the temperature range from 200K to 300K and the pressure range from 1MPa to 30MPa ,and they obtained 63data. The uncertainty of the measurement was not mentioned in the reference. As for the purity of sample, according to the report ,the sample didn't contain organic impurity, and the content of water didn't exceed 100ppm.

In 1993, using a capillary viscometer, Ripple<sup>[6]</sup> measured the saturated liquid dynamic viscosity of R134a, and he obtained 14 experimental data. The measurement was performed in the temperature range from 250K to 306K. According to the report, the claimed uncertainty of the measurement was 35 %, and the purity of the sample was greater than 99.98%.

Han Zhongli<sup>[7]</sup> measured the saturated liquid dynamic viscosity in 1994 ,and he obtained 21 data. The measurement was performed in the temperature range from 233.15K to 333.15K. The purity of the sample was 99.95%. According to the reference ,using their device to measure the dynamic viscosity of water at 40 ,the uncertainty of the measurement was 0.06%.

In 1995 ,Tsvekov<sup>[8]</sup> measured the superheated vapor dynamic viscosity of R134a, and he obtained 11 data.

All above are listed in table 1.

Table I. show most of the measurement are focused on saturated liquid, and the subcooled liquid. The superheated vapor experimental data are only Tsvetkov's 11 data and Lavrenchenko's 11 data.

The author analyze all the experimental data .Through graphics analysis, the author found that Diller's data have obvious error, and in the reference [12,13] Assael points out the problem ,too. Finally, the author select 256 data from all the data .The selected data are in the saturated liquid phase, subcooled liquid phase and superheated vapor phase. The temperature range is from 213K to 400K, and the Pressure range is from 0.1MPa to 50MPa.

# 3. FOUNDATION OF THE CORRELATION FOR DYNAMIC VISCOSITY OF R134a

According to the statistical thermophysics, the dynamic viscosity is not only correlated to temperature, but also correlated to the pressure or density. After thorough study on the dynamic viscosity, the authors propose the correlation for dynamic viscosity:

$$h = \sum_{i=0}^{N1} f_i(T_r) r_r^i$$

where N1 and  $f_i(T_r)$  are determined by optimizing on the basis of experimental data

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Finally, we obtained the correlation as below:

$$h = f_0(T_r) + f_1(T_r) \cdot r_r + f_2(T_r) \cdot r_r^2 + f_3(T_r) \cdot r_r^3 + f_4(T_r) \cdot r_r^4 + f_5(T_r) \cdot r_r^5 + f_6(T_r) \cdot r_r^6$$

where :  $f_0(T_r) = a_1/T_r + a_2T_r$ 

$$f_1(T_r) = a_3 + a_4/T_r + a_5/T_r^2$$

$$f_2(T_r) = a_6 + a_7/T_r + a_8/T_r^2$$

$$f_3(T_r) = a_9 + a_{10}/T_r + a_{11}/T_r^2$$

$$f_4(T_r) = a_{12} + a_{13}/T_r^3 + a_{14}/T_r^6$$

$$f_5(T_r) = a_{15} + a_{16}/T_r + a_{17}/T_r^2$$

$$f_6(T_r) = a_{18} + a_{19}/T_r^4 + a_{20}/T_r^6$$

where 
$$T_r = T/T_c$$
,  $r_r = r/r_c$ 

 $a_i$  (i=1,2,,20) is listed in table 2.

The units:  $h: mPa \cdot s T \in K \rho \in kg \cdot m^{-3}$ .

### 4. TEST AND COMPARITION OF THE CORRELATIONS

In order to analyze and compare the calculating accuracy of the correlations for the dynamic viscosity of R134a, the authors compare the correlations according to their application range. The comparison has been performed in saturated liquid phase, subcooled liquid phase and superheated vapor phase.

The correlations used are listed below:

Kumagai<sup>[1]</sup> proposed a correlation for the saturated liquid dynamic viscosity of R134a in 1991:

$$lnh = A + B/T + CT + DT^2$$
(2)

A correlation for saturated liquid dynamic viscosity of R134a was presented by Oliveira<sup>[4]</sup> in 1993:

$$h = \exp\left(\sum_{i=0}^{4} a_i T^{-i}\right) \tag{3}$$

Diller<sup>[5]</sup> proposed a Correlation for saturated and subcooled liquid dynamic viscosity of R134a in 1993:

$$h^{-1} = 242.25 \times \exp(-1.607 \times 10^4/T^2) \times (102.03 \times v - 0.061)$$
 (4)

Ripple<sup>[6]</sup> proposed a correlation for saturated liquid dynamic viscosity of R134a in 1993:

$$h^{-1} = B \left( \frac{1}{r} - \frac{1}{r_0} \right)$$
 (5)

A correlation for saturated liquid dynamic viscosity of R134a was proposed by Han Zhongli<sup>[7]</sup> in 1994:

$$\ln h = 8559810 - 5085909/T - 0.03899179T + 0.00003557719T^{2} (6)$$

The correlation for the rarefied gas dynamic viscosity of R134a was proposed by Krauss<sup>[9]</sup> in 1993:

$$h = 0.269566\sqrt{T}/(s^2 \times \Omega_n(T^*)) \times 10^{-3}$$
 (7)

Latini<sup>[10]</sup> proposed a correlation for the saturated and subcooled liquid dynamic

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$$\eta^{-1} = A(1/(C - T_r) - 1) \tag{8}$$

A correlation proposed by Oliveira<sup>[11]</sup> is valid near the saturated liquid line 1n 1993:

$$h = \exp(-391.01/T + 4.69 - 1.67 \times 10^{-2}T)$$
 (9)

A correlation proposed by Assael<sup>[12]</sup> in 1995 ,which can be used to calculate saturated liquid dynamic viscosity and subcooled liquid dynamic viscosity

$$log(\eta^*/R_{\eta}) = \sum_{i=0}^{7} a_i v_r^{-i}$$
 (10)

where 
$$\eta^* = 6.035 \times 10^8 (1/MRT)^{0.5} \eta v^{2/3}$$

The data used to test the correlation are divided into several groups:

The experimental data in the saturated liquid phase contain the 8 data obtained by Kumagai<sup>[1]</sup>,the 17 data obtained by Oliveira<sup>[4]</sup>,14 data obtained by Ripple<sup>[6]</sup> and the 21 data obtained by Han Zhongli<sup>[7]</sup>. There are 60 data all together. The data in the subcooled liquid phase contain Okubo's 81 data<sup>[3]</sup>,43 data obtained by Oliveira<sup>[4]</sup> and Diller's 63 data<sup>[5]</sup>. There are 187 data all together. The data in the superheated vapor phase contain Lavrenchenko's 11 data<sup>[2]</sup> and Tsvetkov's 11 data<sup>[8]</sup>.

The correlations that can be used to calculate the saturated liquid dynamic viscosity of R134a are correlation(1),(2),(3),(4),(5),(6),(8),(9) and (10). The correlation that can be used to calculate the subcooled liquid dynamic viscosity of R134a are correlation (1),(4),(8),(10). Though correlation(8) can be used to calculate the liquid dynamic viscosity at 1atm, when the pressure varies, the calculated deviation is big. So in this paper, the author use correlation(1),(4),(10) to calculate the subcooled

liquid dynamic viscosity. And the correlation(1) is the only one that can be used to calculate the superheated vapor dynamic viscosity. The results are given in the table 35.

From table 35., the mean deviation of correlation(1) in saturated liquid phase is 1.4%; in subcooled liquid phase is 2.486%; in superheated vapor phase is 0.24%. Though the mean deviation of correlation(2),(6) is less than the mean deviation of correlation(1) in saturated liquid phase, their maximum deviation is greater than the maximum deviation of correlation(1),and correlation(2),(6) are valid only in the saturated phase ,they can't be used in other phases. The correlation that can be used in all phases is not seen by the authors. Using correlation (1) to calculate all the data , we find the mean deviation is 2.15%.

## 5. CONCLUSION

A new correlation for the dynamic viscosity of R134a is proposed in this paper. This correlation is valid in both liquid and vapor phase. The temperature range is from 213K to 413K, and the pressure range is from 0.1MPa to 50 MPa. This correlation has wide application range and high accuracy.

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Table1. The recent experimental study on dynamic viscosity of R134a

investigator	ref.	year	temp. (K)	pres.(MPa)	uncert ainty	method	state	purity	No
Kumagai	[1]	1991	273-343	saturated	0.5%	capillary	sat liq	99.8 %	8
Lavrench	[2]	1992	257-404	0.318-6.437	-	-	liq,ga s	-	34
Okubo	[3]	1992	213-423	1.5-30	1.3%	capillary	sub liq	99.9 %	81
Oliveira	[4]	1992	237-343	0.664-50	0.6%	vibrating wire	sat & subliq	99.9 %	60
Diller	[5]	1993	175-300	1-30	-	-	sat & subliq	-	93
Ripple	[6]	1993	250-306	saturated	3-5%	capillary	sat liq	99.9 %	14
Han Zhongli	[7]	1994	233-333	saturated	-	capillary	sat liq	99.9 %	21
Tsvetkov	[8]	1995	240-400	0.1	1-3%	-	gas	-	11

Table 2.The coefficients in correlation(1)

$a_1$	-4.576478787131452E-002	$a_{11}$	4.069435820983251E-001
$a_2$	1.728979887079300E-002	$a_{12}$	-10.385097450008580
$a_3$	5.253045820843735	$a_{13}$	-2.159082993944610E-001
$a_4$	2.579075908769767	$a_{14}$	3.566635600383745E-003
$a_5$	-9.510553925147035E-001	a <sub>15</sub>	2.823605744716981
$a_6$	-16.012581398641750	a <sub>16</sub>	-2.044809333539607E-001
$a_7$	-3.044821593570919	a <sub>17</sub>	1.211127912244915E-001
$a_8$	3.303888985018212E-001	a <sub>18</sub>	-2.802395840416193E-001
$a_9$	18.624039221137270	a <sub>19</sub>	2.713093488292830E-003
a <sub>10</sub>	1.087659459212924	$a_{20}$	-3.888946775909761E-004

Table 3. Comparison in saturated liquid phase (data from ref.[1][4][7])

correlation	maximum	mean	correlation	maximum	mean
	deviation	deviation		deviation	deviation
1	7.19%	1.40%	6	8.66%	1.24%
2	8.80%	1.36%	7	13.79%	3.12%
3	9.33%	1.71%	8	12.57%	2.69%
4	9.24%	4.09%	9	10.70%	2.06%
5	7.27%	1.82%			

Table 4. Comparison in subcooled liquid phase (data from ref.[3,4,5])

correlation4	correlation10	correlation1
mean deviation	mean deviation	mean deviation
3.74%	3.147%	2.486%

Table 5. Comparison in superheated vapor phase(data from ref.[2,8])

correlation1	correlation7
mean deviation	mean deviation
0.24%	0.47%